SRF and warm RF components for LEReC

Sergey Belomestnykh
Collider-Accelerator Department, BNL
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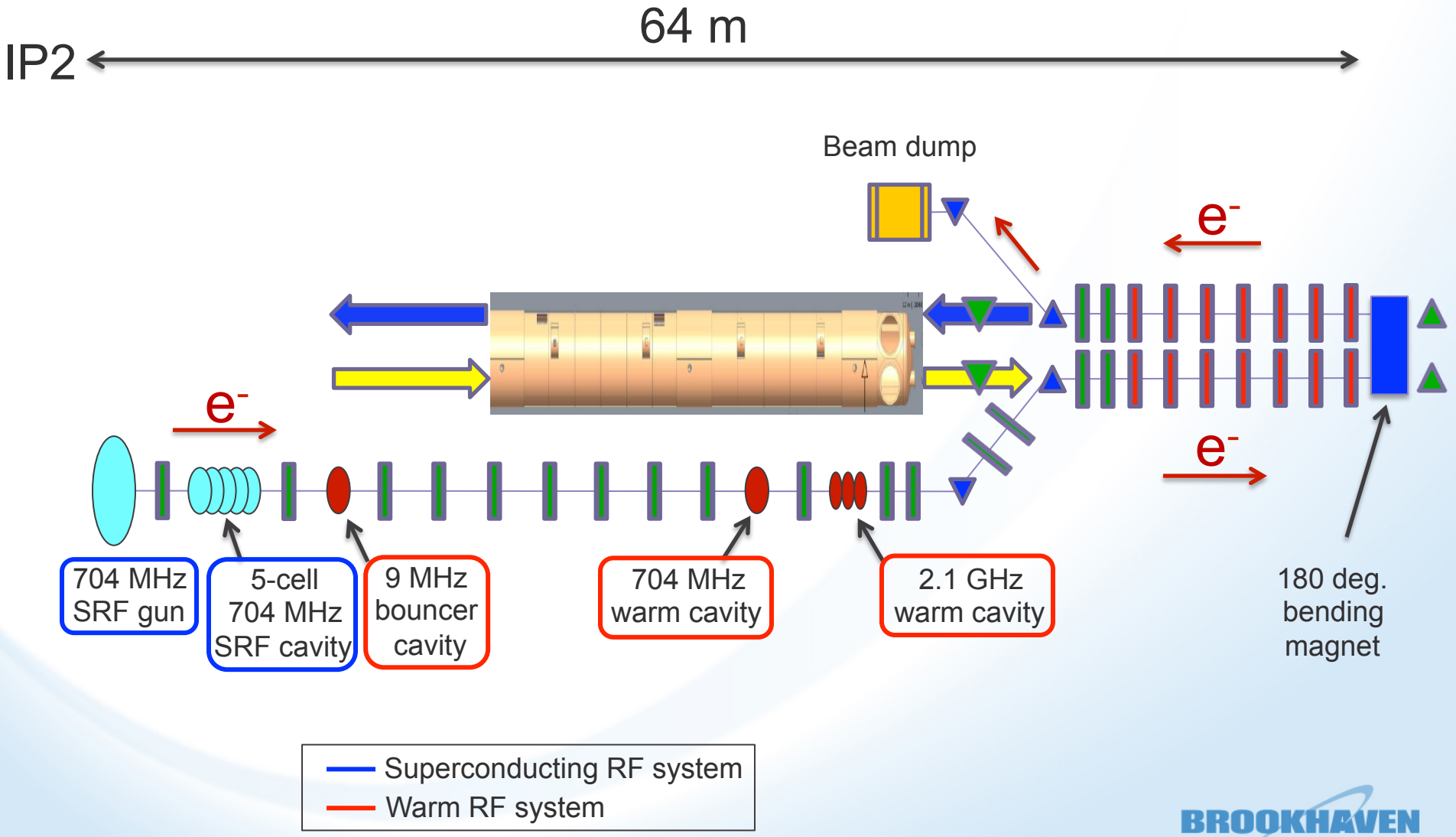
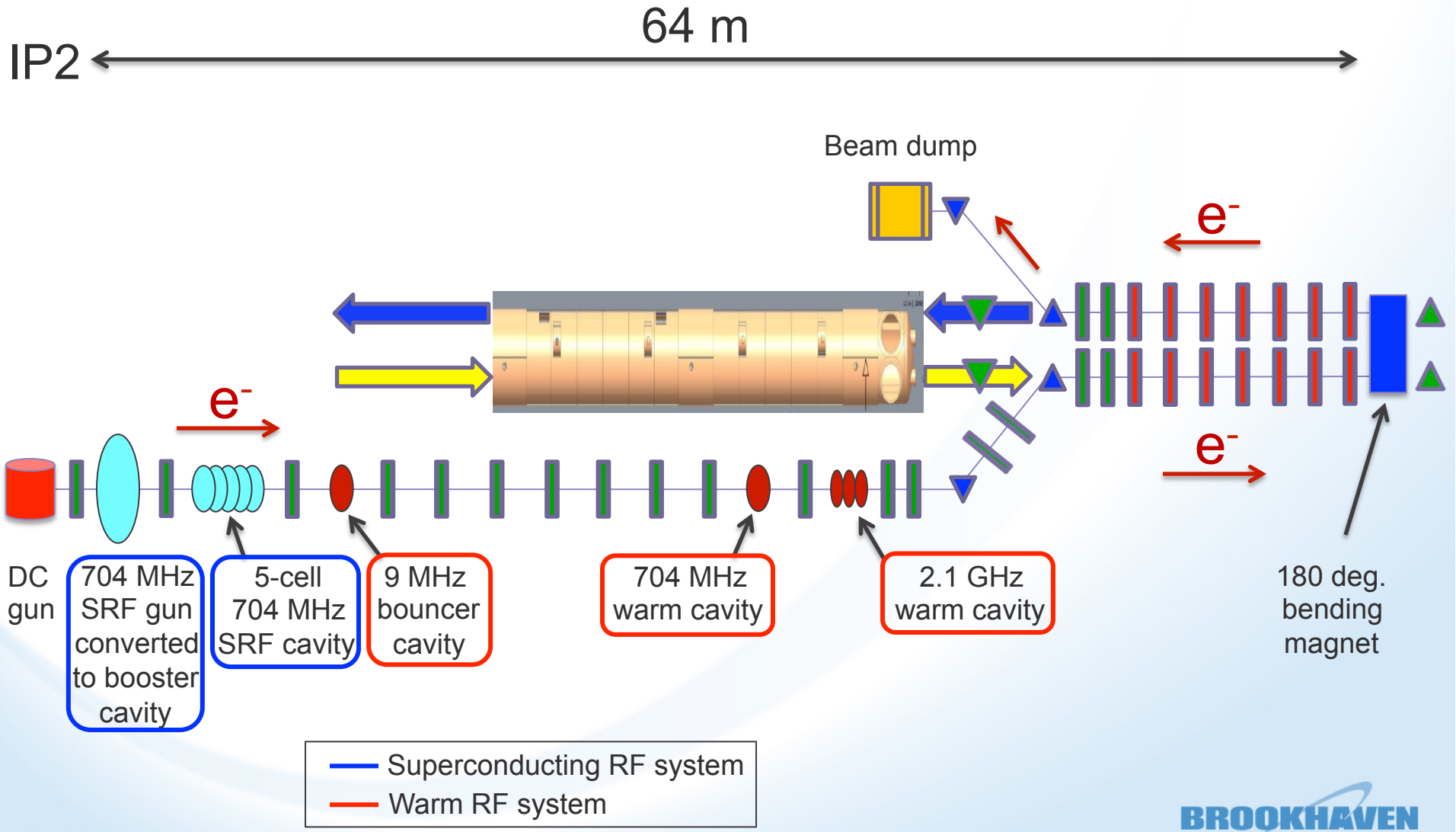
Outline

- Overview: layout and general description of the SRF and RF components for LEReC linac
- Description of SRF and warm RF systems:
  - 704 MHz SRF gun
  - 704 MHz 5-cell SRF cavity
  - 9 MHz bouncer cavity
  - 704 MHz warm RF cavity
  - 2.1 GHz warm RF cavity
- Summary

LEReC-I (baseline option): Gun to dump SRF gun



LEReC-I (parallel path): Gun to dump
DC gun + SRF gun as a booster cavity

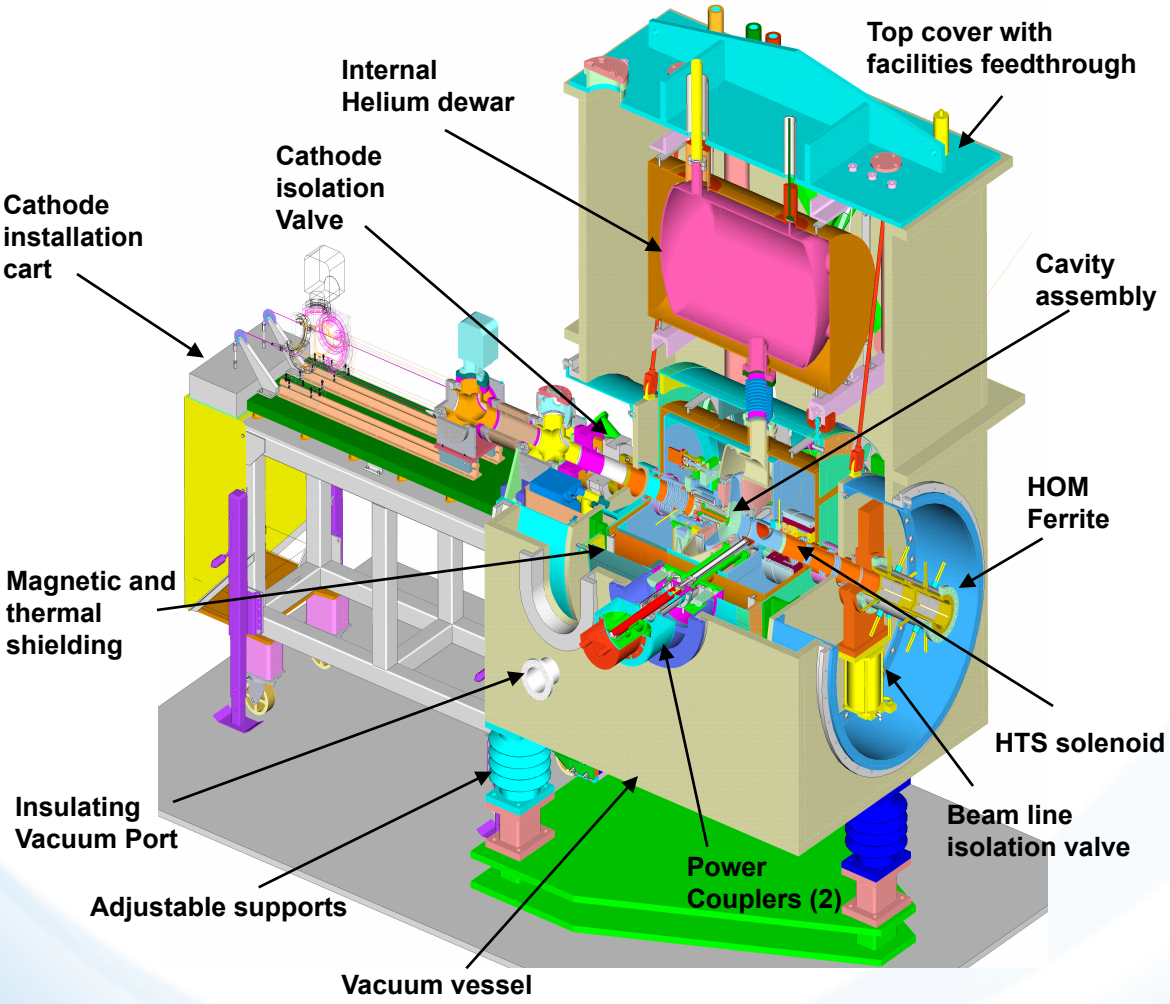


Overview

There are five SRF/RF systems in the LEReC linac set up:

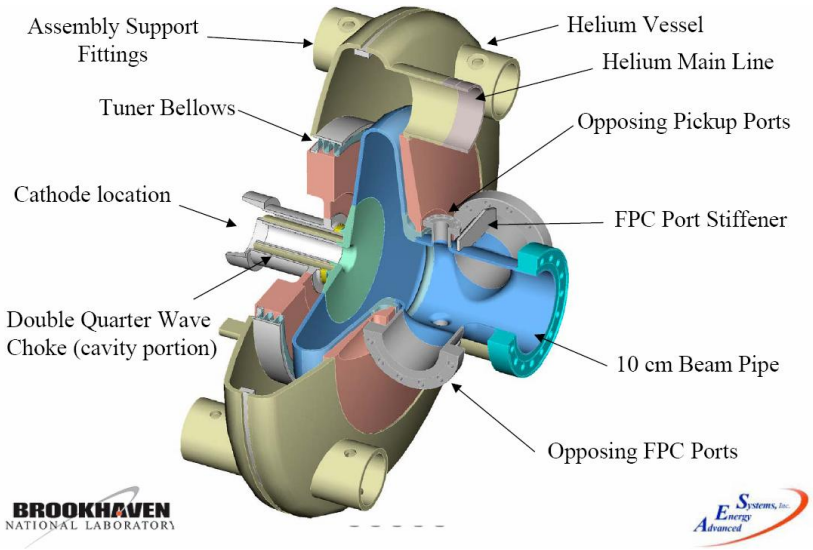
- *704 MHz SRF photoemission gun* providing a 1.6 to 2.0 MeV beam of electrons – requires some modification for LEReC. High power CW RF system will use two amplifiers. One will be a new 65 kW high power RF amplifier, the other will be a re-tubed 50 kW IOT amplifier relocated from ERL. For LEReC-II the 50 kW amplifier will be replaced with another 65 kW unit.
- If a DC gun option is selected, the gun SRF cavity can be converted into a booster cavity with a maximum voltage of 1.6 MV.
- *704 MHz 5-cell SRF cavity* operating at a voltage up to 0.9 MV for bunch lengthening – relocated from R&D ERL. 20 kW CW RF system for the 5-cell cavity – shared with the CeC PoP linac.
- *9 MHz bouncer cavity* with associated RF transmitter for beam loading correction – repurposed spare system for RHIC.
- *704 MHz warm cavity* operating at a voltage up to 430 kV for energy spread correction – new design. 50 kW CW RF amplifier – retuned (from 500 MHz) IOT amplifier shared with the CeC PoP bunching cavities. One more 704 MHz warm cavity will be added for LEReC-II
- *2.1 GHz warm cavity* operating at a voltage up to 100 kV cavity for further correction of the energy spread – new design. 20 kW CW RF system for the warm cavity – new RF system.

SRF photoemission electron gun



- A 704 MHz ½-cell SRF gun with an independently cooled (by helium gas) demountable cathode stalk uses a multi-alkali photocathode.
- An RF choke-joint supports the photocathode stalk and has triangular grooves for suppression of multipacting.
- Two Fundamental Power Couplers (FPCs) are designed to deliver up to 1 MW of RF power. Will need only 100 kW for LEReC.
- The gun's Qext will have to be adjusted from 5.5e4 to 4.1e5. This will be accomplished with 3-stub waveguide transformers.
- A high-temperature superconducting solenoid is located inside the cryomodule.
- HOM damping is provided by an external beamline ferrite load with a ceramic break.
- A photoemission average beam current of 1 uA has been achieved recently in a pulsed mode at 1.25 MV with a bunch charge of ~8 pC.

SRF gun parameters



RF frequency	703.6 MHz
Cavity active length	8.5 cm (0.4 cell)
Maximum energy gain	2.0 MeV
Maximum field at the cathode	26.7 MV/m
E_{acc} at 2 MV	23.5 MV/m
Installed RF power	120 kW
R/Q	96.2 Ohm
Geometry factor	112.7 Ohm
Cavity operating temperature	2 K
Cathode operating temperature	80 K
Cathode RF losses (80 K) at 2.0 MV	226 W
Q_{ext}	3×10^5 to 6×10^5
Frequency tuning range	1 MHz
Required RF power	60 kW (LEReC-I) / 100 kW (LEReC-II)
Installed RF power	115 kW / 130 kW

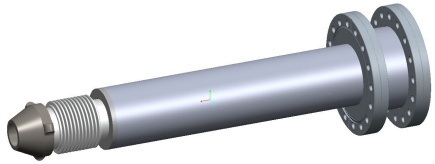
More details on the SRF gun performance in "SRF gun commissioning progress" by Wencan Xu

Major RF components for the SRF gun

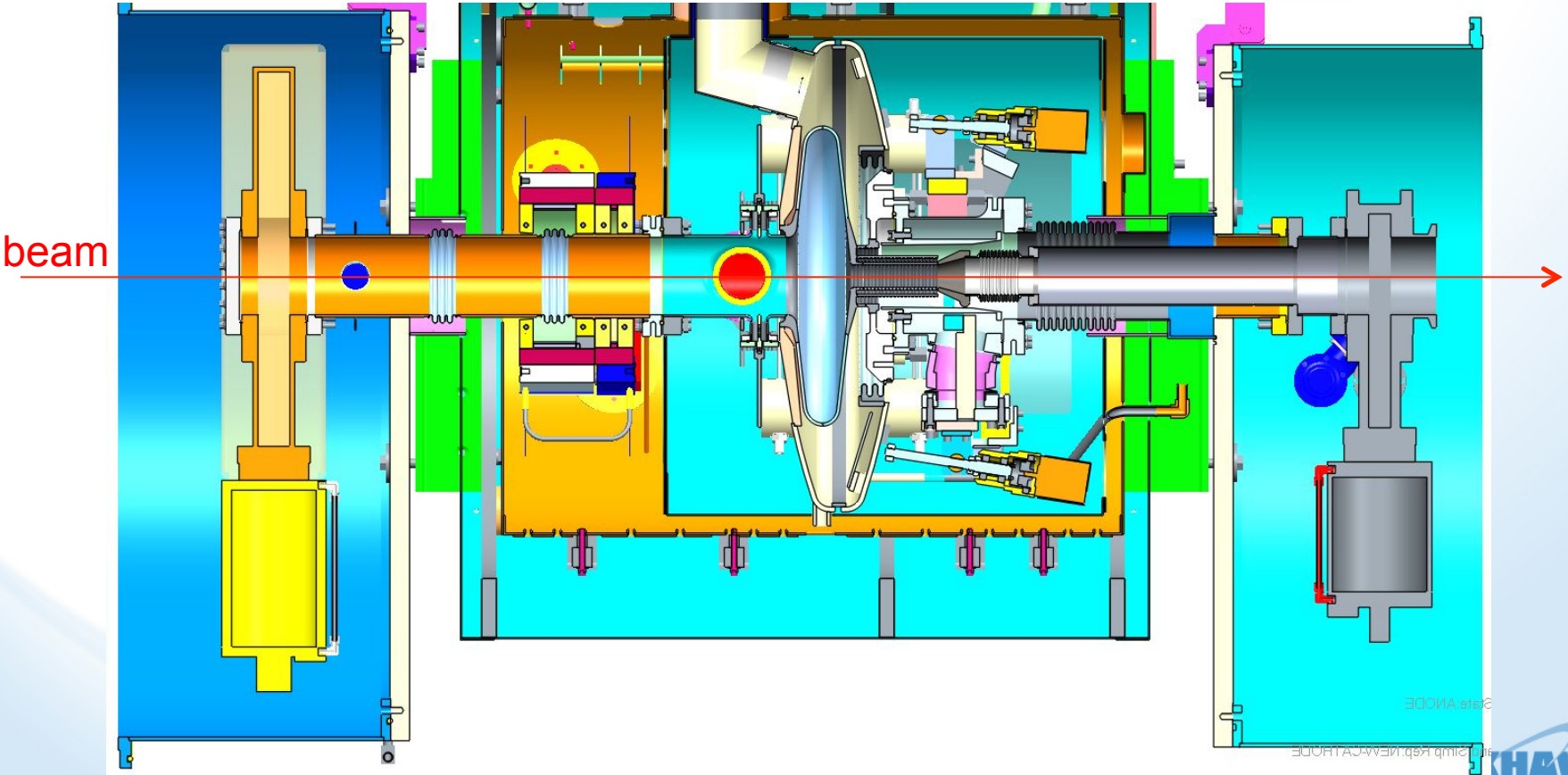
- The gun will be re-located from the R&D ERL in building 912 to IR2
- As relocation of the 1 MW klystron to IR2 in unfeasible, a new RF system will be built including
  - One new 65 kW CW RF amplifiers and a re-tubed 50 kW IOT amplifier relocated from ERL. Two amplifiers are required only for the baseline option of LEReC-I, otherwise a single 65 kW amplifier is sufficient;
  - Circulators, RF loads, transmission line components;
  - New digital LLRF.
- New cathode will be tested in December/January. It is expected to resolve multipacting issue and allow the gun to operate in CW mode in the required energy range.
- High power 3-stub WG transformers will be used to adjust RF coupling of the FPCs to LEReC specifications.

SRF gun conversion into a booster cavity

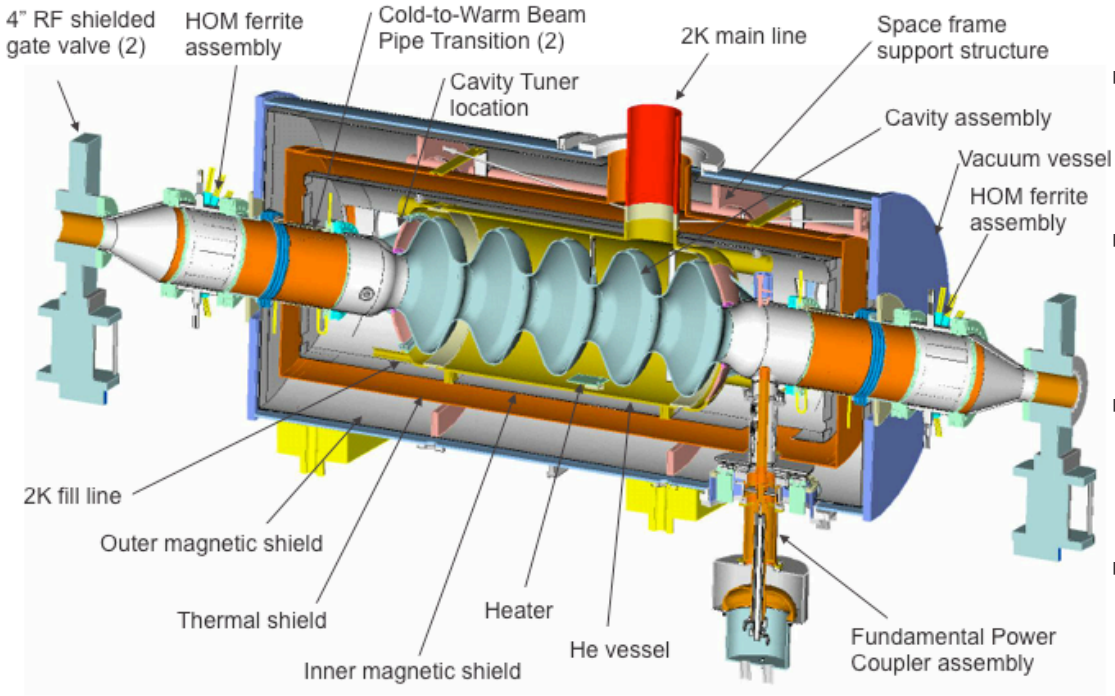
- A new beam pipe insert will be designed and built to replace the cathode stalk insertion system.



- The cryomodule will be flipped around.



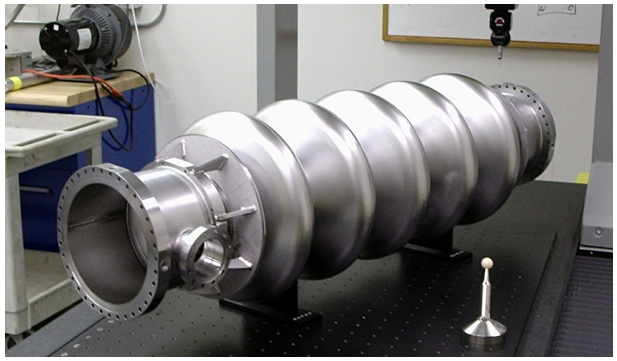
5-cell SRF cavity (BNL1)

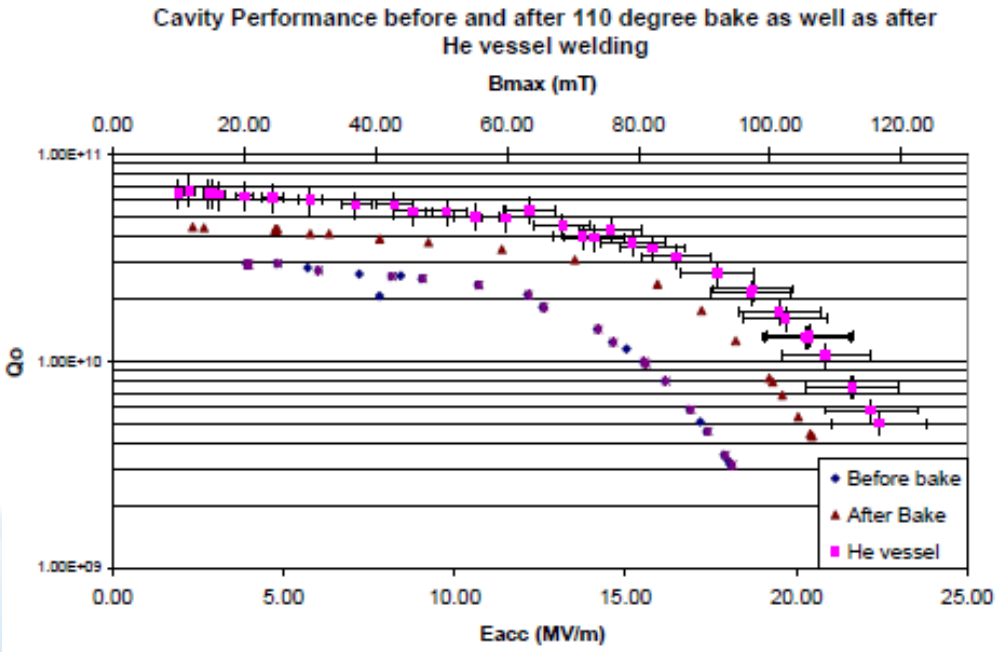


- Fundamental mode resonates at 703.6 MHz.
- Large (24 cm dia.) beam tubes allow all HOMs to propagate toward room-temperature ferrite HOM dampers.
- The cutoff frequency of beam pipes is 790 MHz, while the first dipole mode is at 810 MHz.
- 50 kW CW fundamental power coupler of the SNS type with water cooled RF window.
- First horizontal test was in March of 2009. Several more tests were carried out after that.

- Mechanical tuner has 112 kHz tuning range, piezo provides 9 kHz fast tuning.
- In CW operation the cavity is quench-limited to 11.5 MV/m due to to the $AlMg_3$ seal located between the NbTi and stainless steel flanges on one of the beam pipes (on the FPC side). However, the cavity performance is more than sufficient for LEReC.
- The cavity is used to provide an energy spread along the bunch for bunch lengthening with an accelerating voltage of 0.155 MV (LEReC-I).
- In LEReC-II it will provide acceleration up to 3 MeV in the ERL configuration.

5-cell cavity parameters



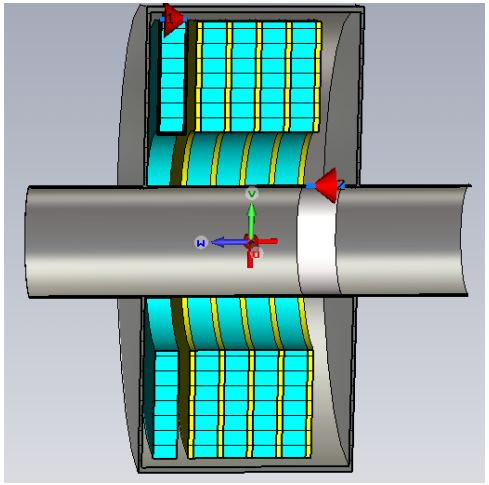


Frequency	703.6 MHz
No. of cells	5
Geometry Factor	225 Ohm
R/Q	404 Ohm
E_{pk}/E_{acc}	1.97
B_{pk}/E_{acc}	5.78 mT/(MV/m)
Length	152 cm
Beam pipe diameter	24 cm
Cavity voltage	0.155 MV / 3 MV (ERL)
Q_{ext}	$1x10^7$
Required RF power	3 kW
Installed RF power	20 kW

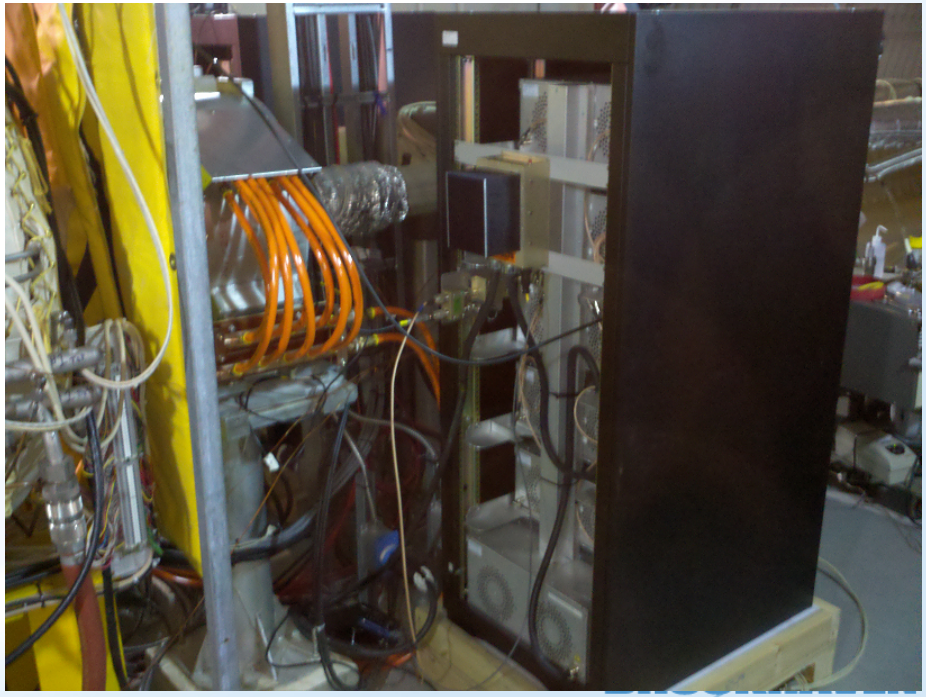
Major RF components for the 5-cell cavity

- The 5-cell cavity will be relocated from the R&D ERL in building 912 to IR2.
- A 20 kW CW solid state RF amplifier will be shared with CeC PoP. The amplifier fabrication is complete at SigmaPhi. Its factory acceptance test is scheduled for next week.
- RF transmission line components will have to be ordered.

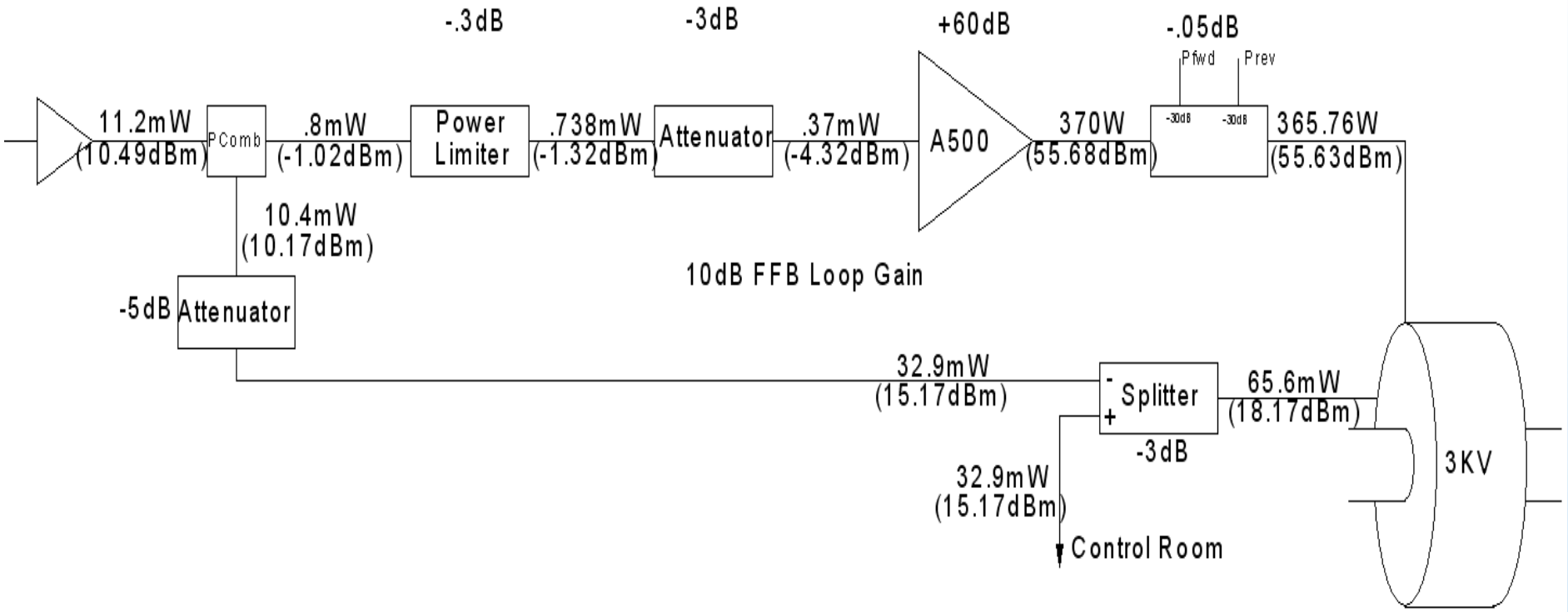
9 MHz bouncer cavity



- This is an existing 9 MHz bouncer cavity spare system.
- It will be installed and used in LEReC to compensate bunch-to-bunch energy variation inside the 30-bunch trains. This variation is due to beam loading effect in other cavities.
- The cavity voltage is up to 3 kV.

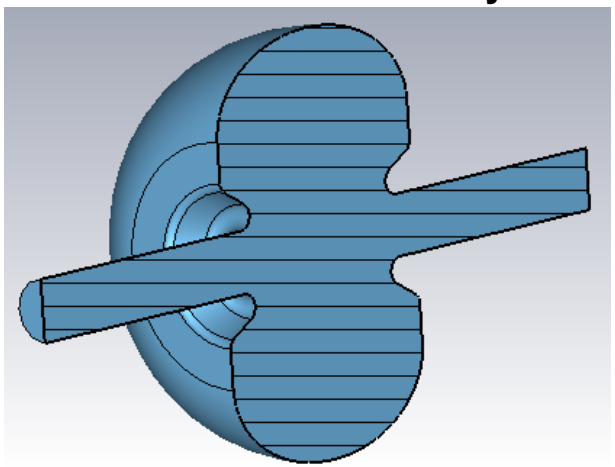


9 MHz bouncer cavity system diagram

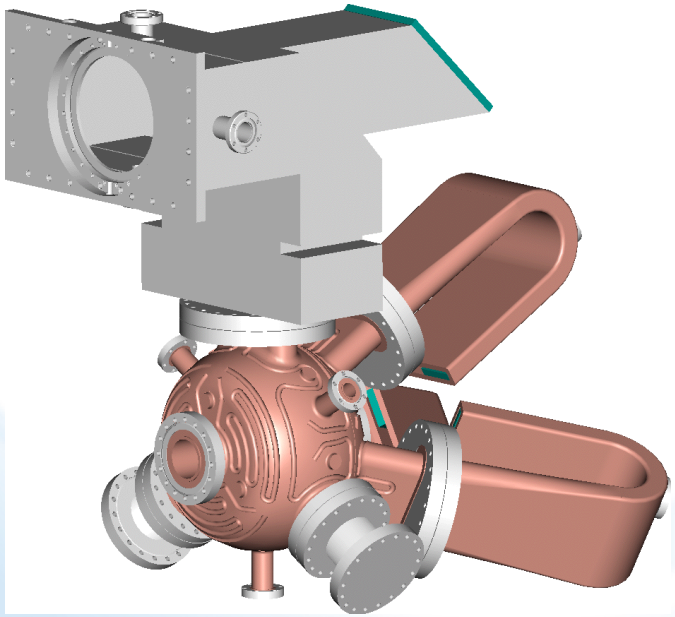


704 MHz warm cavity

704 MHz LEReC cavity



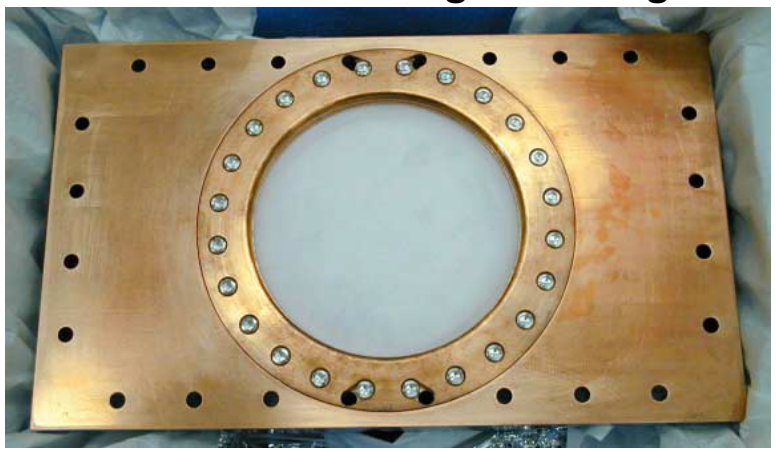
714 MHz NLC damping ring cavity



- A ingle cell 704 MHz warm cavity is used to correct the beam energy spread.
- The cavity is designed for an accelerating voltage up to 430 kV as will be required for LEReC-II. Only 78 kV is required for LEReC-I.
- We will borrow design of some components from the 714 MHz cavity developed at LBNL for the NLC damping ring.
- The cavity shape was re-optimized as we have different frequency, beam pipe diameter and do not need HOM dampers.
- The dissipated power at maximum voltage will be 25.5 kW.
- We plan to use an RF window originally design for the NLC damping ring cavity at LBNL and further developed at JLab.
- There will be a plunger-type frequency tuner.
- The RF design is in progress and we plan to complete it in December.

704 MHz warm cavity parameters and major RF components

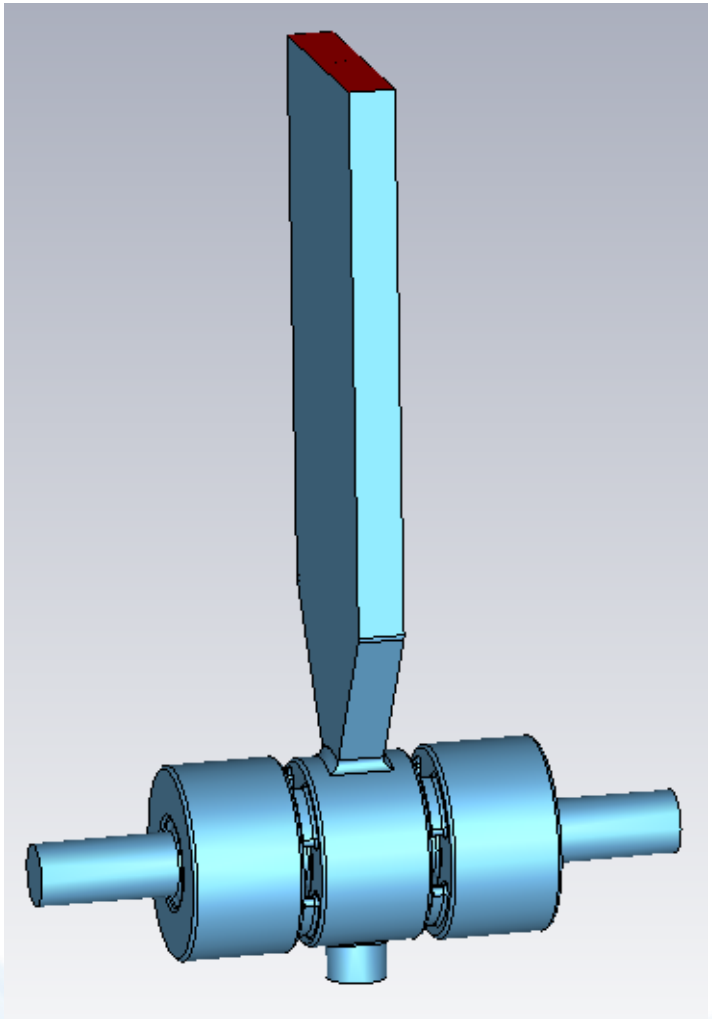
RF window in waveguide flange



Frequency	703.6 MHz
No. of cells	1
R_{sh}	7.25 MOhm
R/Q	250 Ohm
Cavity voltage	430 kV
Required RF power	25.5 kW
Installed RF power	50 kW

- The cavity will be ordered from industry.
- The RF window will be produced by JLab (they have made several such windows for LANL).
- A 50 kW RF amplifier is a 50 kW, 500 MHz IOT amplifier for CeC PoP re-tuned to 704 MHz.
- WR1150 components, coaxial line, circulator, RF load will be ordered.
- Digital LLRF is a copy of existing LLRF developed for other RF systems at C-AD.

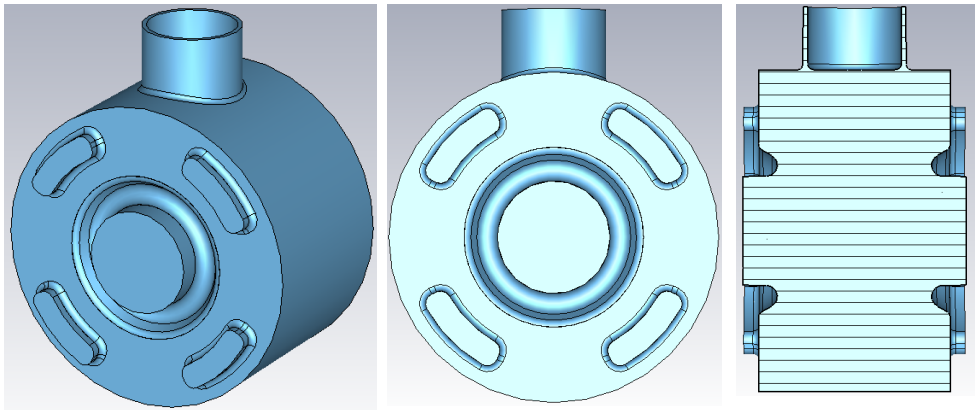
2.1 GHz warm cavity



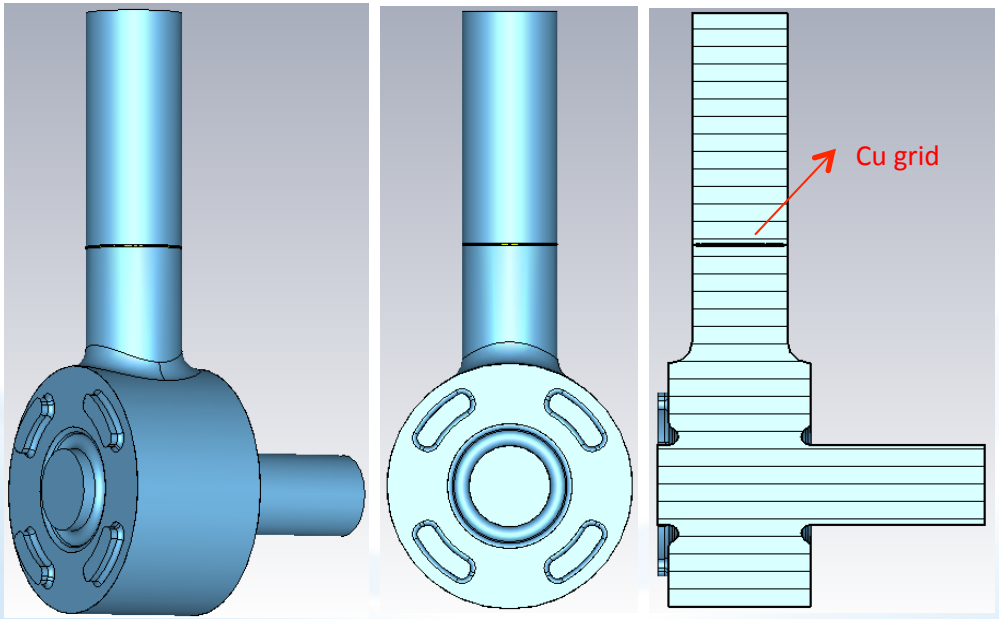
- The third harmonic cavity is used to “fine-tune” the beam energy spread.
- This is a 3-cell copper structure with magnetic coupling between cells.
- The cavity is designed for an accelerating voltage up to 100 kV as will be required for LEReC-II. The voltage in LEReC-I configuration is only 6 kV.
- The dissipated power at maximum voltage will be 1.75 kW.
- We plan to use a CEBAF-type RF window.
- There will be two plunger-type frequency tuners operating in parallel. The tuners will be located on the end cells.
- One ion pump will maintain the cavity vacuum. Another small pump will be located near the RF window.
- The RF design is complete and mechanical design has started.

2.1 GHz cavity parameters

Center cell with tuner port



End cell with pumping port



Frequency	2.11 GHz
No. of cells	3
R_{sh}	5.71 MOhm
R/Q	487 Ohm
Frequency tuning range	6.1 MHz
Cavity voltage	100 kV
Required RF power (including beam loading compensation)	5.5 kW
Installed RF power	10 kW

Major RF components for the 2.1 GHz cavity

- The cavity will be ordered from industry or built in collaboration with a national lab, e.g. SLAC.
- Fundamental power coupler will use a CEBAF RF window, available from industry.
- A new 10 kW RF amplifier will be based on solid state technology, a less expensive option.
- WR430 components, circulator, RF load will need to be purchased.
- Digital LLRF will be based on generic RHIC LLRF platform.

CEBAF RF window

Timeline

- FY2015:
  - continue commissioning of the SRF gun;
  - finish RF and mechanical design of the 704 MHz warm cavity, engineering design review, place orders for the cavity, RF window and other RF components;
  - finish mechanical design of the 2.1 GHz cavity, engineering design review, place orders for the 2.1 GHz cavity, FPC, RF amplifiers, other RF components.
- FY2016:
  - receive and inspect components;
  - high-current commissioning of the SRF gun and 5-cell cavity in CW mode (bldg. 912);
  - modification of the gun into a booster cavity if necessary.
- FY2017: installation in IR2, commissioning.
- FY2018: commissioning with RHIC beams and low energy Au operation.

Summary

- There will be five SRF/RF systems in LEReC: 704 MHz SRF gun and 5-cell SRF cavity; 9 MHz bouncer cavity; new 704 MHz and 2.1 GHz warm cavities.
- The SRF gun commissioning with high beam currents in CW mode will have to be completed in bldg. 912: new cathodes; improved cathode cooling; new HTS solenoid leads. The gun's FPC coupling will be modified using 3-stub waveguide transformers.
- For the parallel path with the DC gun, the gun SRF cavity can be converted into a booster cavity.
- The 5-cell cavity is ready for LEReC, needs to be relocated.
- A complete 9 MHz bouncer cavity system is available from RHIC, will be used for beam loading compensation.
- A new single cell 704 MHz warm cavity will be designed and ordered from industry. Its RF design is in progress, will be complete in December. There are a number of companies that can manufacture the cavity. The RF window will be built according to JLab's specifications in collaboration with R. Rimmer.
- RF design of the new 3-cell third harmonic cavity operating at 2.1 GHz is complete. Mechanical design is in progress. The cavity can be fabricated by industry or in collaboration with a national lab.

Thank you!